2018 IEEE SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY, SIGNAL AND POWER INTEGRITY

EMC+SIPI 2018

July 30 – August 3, 2018 Long Beach, CA

Your Port for EMC+SIPI Compliance

Far-Field Pattern Measurement and Simulation of VHF Antenna at 60 MHz for Europa Clipper mission

Yasser Hussein, Joshua Miller, Vachik Garkanian, and Emmanuel Decrossas

Jet Propulsion Laboratory,
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA, 91009

Outline

- Summary
- Purpose of Europa Mission
- Testing Techniques Overview
- VHF Antenna Design
- Ground Effect Simulation and Analysis
- Simulation and Measurements Results
- Conclusions and Acknowledgment

Summary:

- This paper presents measurements and simulations of a VHF folded dipole operating at **60 MHz** for NASA's upcoming Europa Clipper mission.
- This antenna will be used as one element of an array of four identical antennas mounted on the Europa Clipper spacecraft to act as a ground penetrating radar that will characterize the surface of Jupiter's icy moon, **Europa**.
- Far-field radiation patterns and reflection coefficients physically measured above a 50×80m near-perfect ground plane are compared to predicted results using software (HFSS).
- Normalized far-field radiation pattern cuts are measured utilizing a biconical antenna and receiver mounted on a flying drone.
- Simulation and measurement results are compared for different setups, which **agreed quite well**.

Europa Mission Overview:

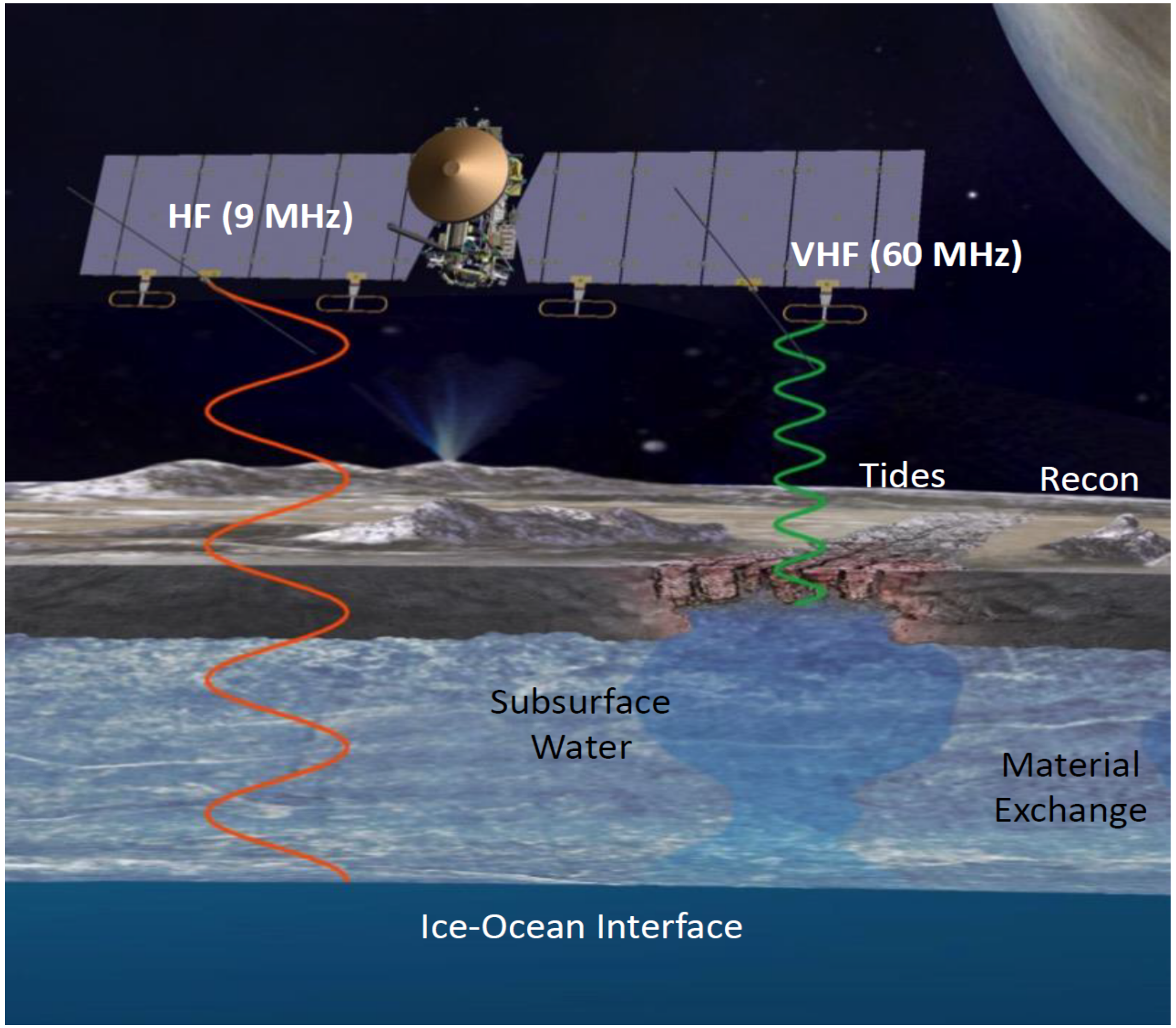
① Characterize the distribution of any shallow subsurface water.

② Search for an **ice-ocean** interface and characterize the ice shell's global structure.

③ Investigate the process governing material exchange among the **ocean, ice shell, surface, and atmosphere.**

④ Constrain the amplitude and phase of **gravitational tides**.

⑤ Characterize scientifically compelling sites, and hazards, for a potential **future-landing** mission.



The 60 MHz antennas under test are part of REASON:

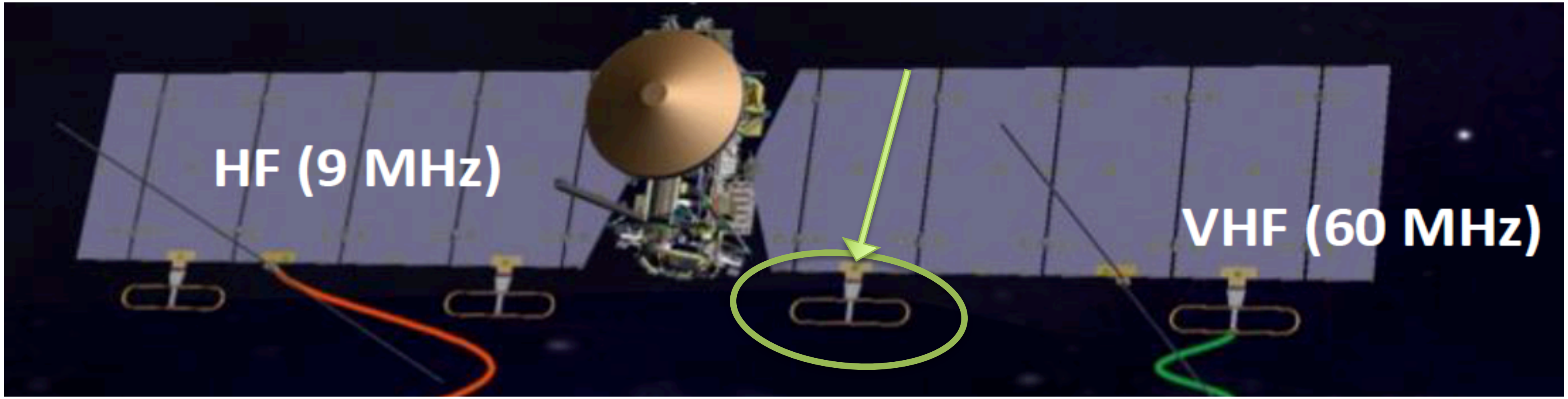
(Radar for Europa Assessment and Sounding: Ocean to Near-surface)

REASON provides four main measurements of Europa:

- **Sounding** to probe the ice shell
- **Altimetry** to determine surface elevations
- **Reflectometry** to study surface roughness
- **Plasma/particles** to detect active plumes through ionosphere characterization

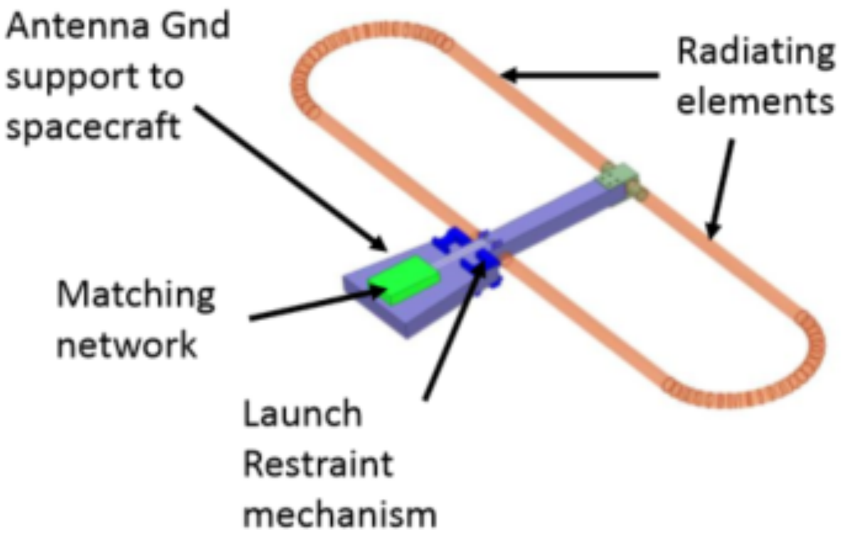
Two radars, **9 MHz and 60 MHz**, on board

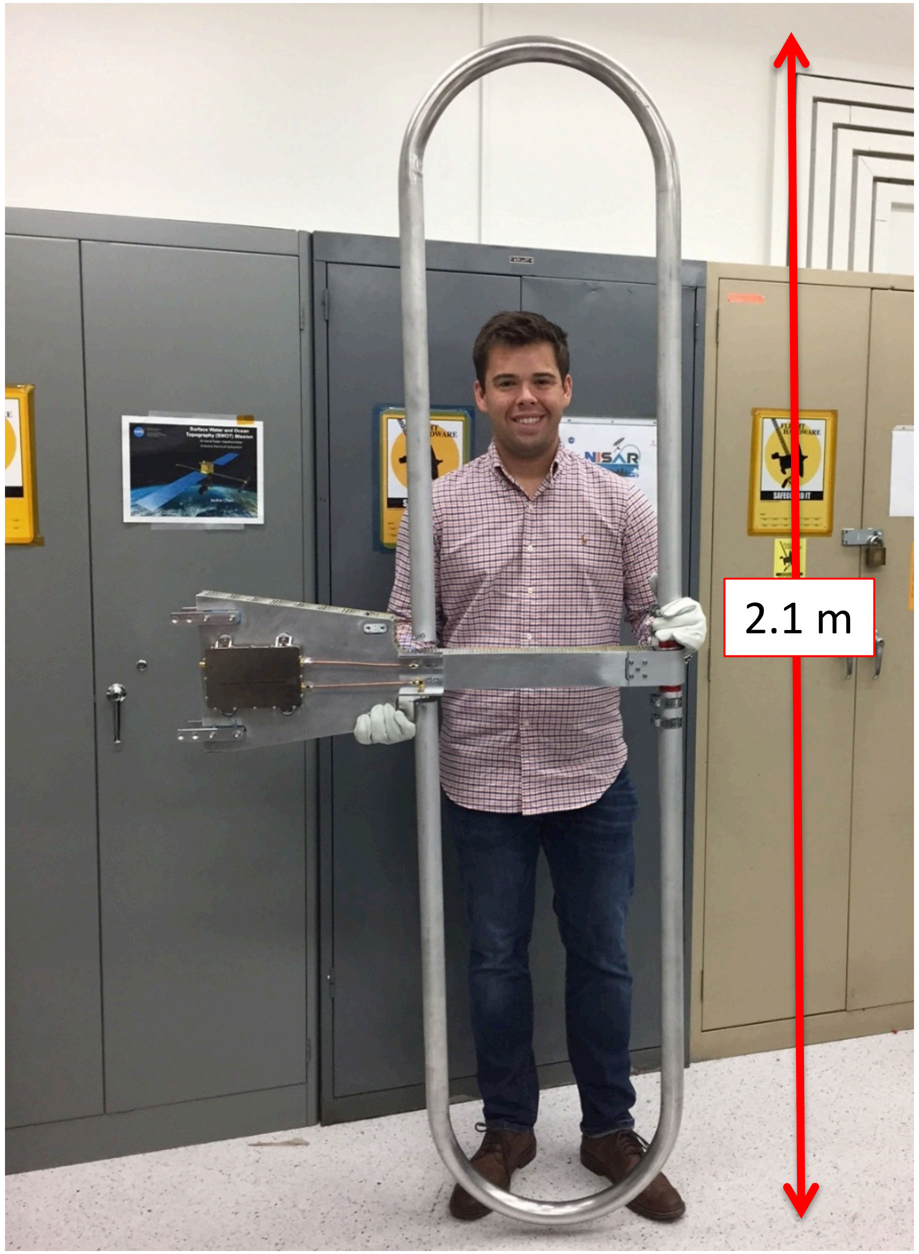
- 9 MHz gives 150m vertical resolution up to 30 km
- 60 MHz frequency gives about a 15m vertical resolution for sounding close to the icy surface up to 4.5km deep
  - Two separate cross-track channels at 60 MHz provide clutter discrimination



VHF Antenna Design:

- The VHF folded dipole prototype consists of **two aluminum tubes**, bent and connected at the top of the antenna.
- A matching network **(balun)** at the base of the antenna is used to feed the radiating element differentially, providing the linearly polarized electrical field.
- Due to the size of the antenna, an **Over the Air Test Site (OATS)** was selected for characterization





A Bit of Testing History:

- Before selecting an **OATS** facility for the measurements, it is necessary to evaluate the suitability of the measurement site using inter-laboratory comparison (**ILCs**) and proficiency tests (**PTs**).
- Proficiency tests (PTs) are ILCs specifically designed to evaluate participants' performance against pre-established criteria. Various ILCs of radiated emission measurements have been proposed since the early 90's by multinational companies such as **Hewlett–Packard** and **IBM**.
- Some of these labs adopted the OATS technique, while the others adopted the use of **semi-anechoic chambers**.
- The reference site used in this paper is **Keysight (formerly Liberty Calibration)** in Kimballton, Iowa, USA.
- Authors reported relatively consistent results for frequencies greater than 30 MHz and less than 1 GHz.
- The site offers a **50 × 80m** near-perfect electrical ground plane to take antenna measurements.

What is the ideal size of an OATS ground plane?

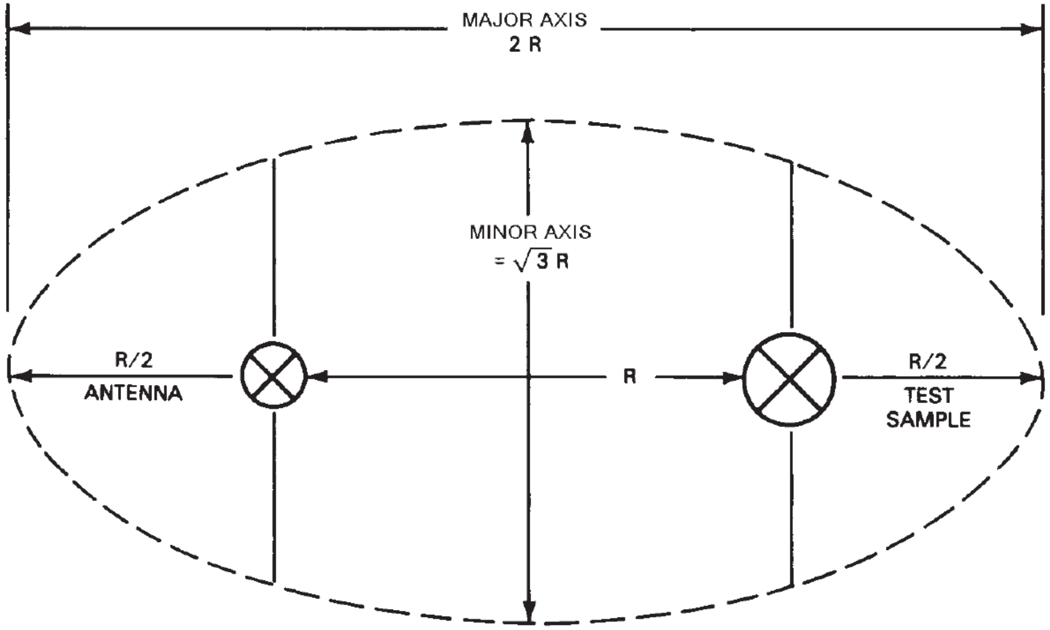
- Guidance on dimensions needed for the construction of an OATS and ground-plane to provide the required reflection characteristics can be found in standards documents such as **ANSI C63.7** or **EN55 022**.
- **ANSI C63.7** analyzed the dimensions required for a good reflecting surface by exploiting the theory of Fresnel Zones.
- The size and shape of the reflecting surface are dependent upon the measurement geometry and whether or not the antenna position or orientation will be changed.
- In general, the reflecting surface is contained wholly within the **obstruction-free area**. It is crucial to have a flexible design and to construct the ground plane so that it can be extended in all directions. **The theoretically minimum ground plane size and shape is derived from the first Fresnel elliptical zone.**

Size analysis of our OATS ground plane using ANSI C63.7

Measurement distance (m)	Frequency (MHz)	Antenna heights (m)		Ellipse axes (m)		Ellipse center (m) (see NOTE 2)
				Major	Minor	
R		h_1	h_2	$2X_1$	$2Y_1$	X_0
3 (see NOTE 1)	30	1	4	9.9	9.5	1.4
		2	4	11.3	11.0	1.5
	100	1	4	5.9	5.3	1.2
		2	4	7.6	7.1	1.4
	1000	1	4	4.0	3.4	1.0
		2	4	6.1	5.5	1.3
10	30	1	4	15.3	12.0	4.7
		2	4	16.3	13.0	4.9
	100	1	4	10.8	6.6	4.3
		2	4	12.4	8.1	4.7
	1000	1	4	7.7	3.6	3.4
		2	4	10.6	5.7	4.5
30	30	1	4	34.5	18.3	14.6
		2	4	35.2	18.9	14.8
	100	1	4	29.5	10.1	13.9
		2	4	31.1	11.1	14.5
	1000	1	4	22.5	4.3	11.0
		2	4	28.0	6.1	13.7

NOTE 1—The dimensions of the first Fresnel ellipse calculated for the 3 m measurement distance at 30 MHz are larger than the recommended obstruction-free area ellipse dimensions in Figure A.1. See Clause 5 and 6.1 for further discussion.

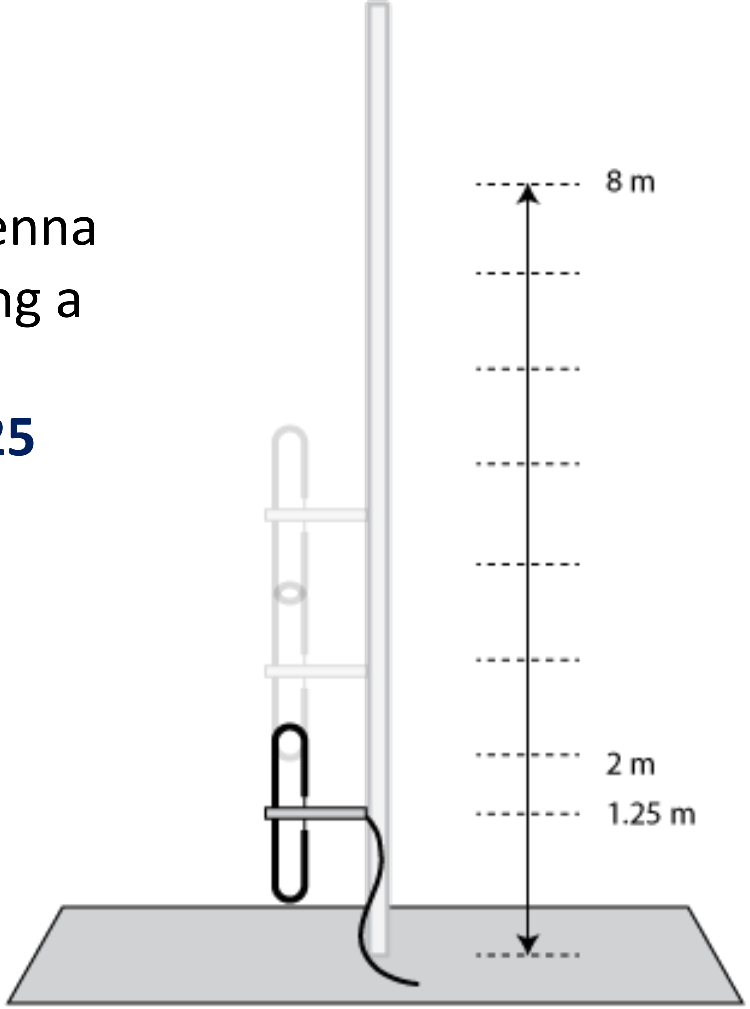
NOTE 2—X_0 is the distance from the position of the EUT to the center of the first Fresnel ellipse. (See Figure A.1.)

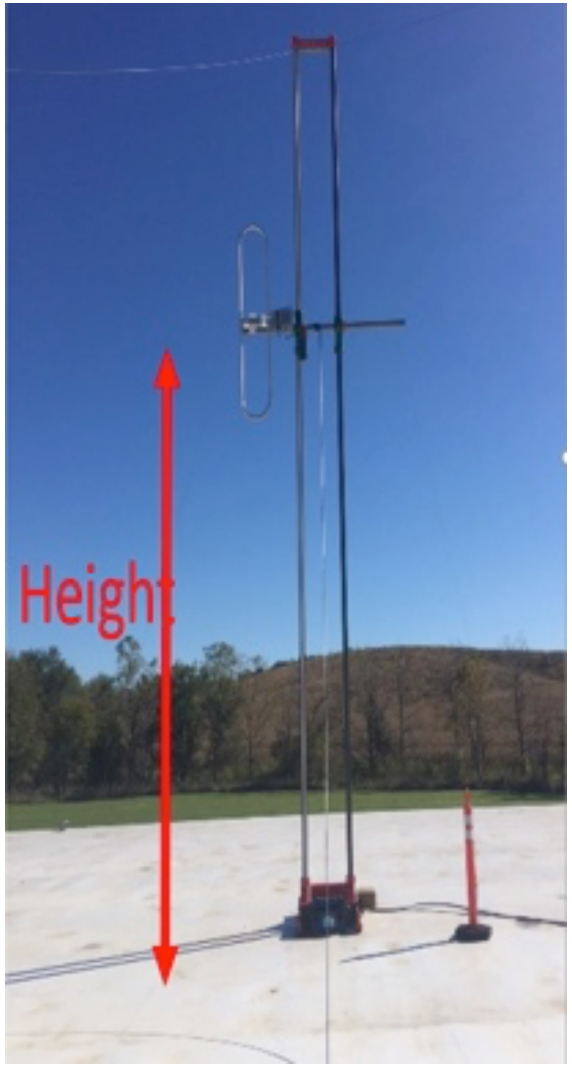


Measurements occur at 25m and 60 MHz – choosing the worst-case setup from the examples in ANSI C63.7 (30 MHz at 30m distance) gives us a required obstruction free area of 34.5m wide by 18.3m tall. This is well within the bounds of our available ground plane surface of 50×80m.

Proposed S- Parameters Measurement Technique:

The reflection coefficients of the antenna mounted vertically are measured using a network analyzer at different heights above the ground plane first from **1.25 meters up to 8 meters**.



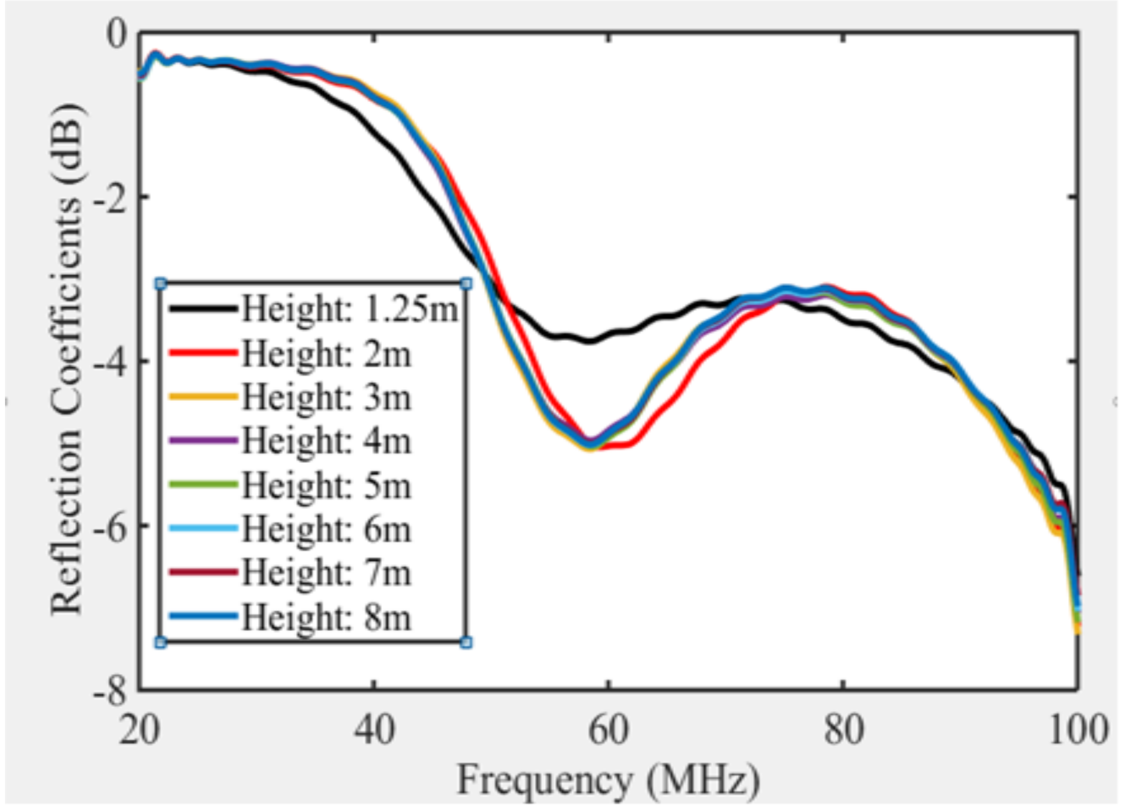


Antenna Mounted on a fiberglass tower with the height between the antenna and ground being varied

S-parameters Measurements

The measured reflection coefficients over the **20-100 MHz** bandwidth do not change when the antenna is mounted above **two meters** as the ground coupling effect is reduced. Far field boundary equation for this antenna **gives L < 2.2 meters.**

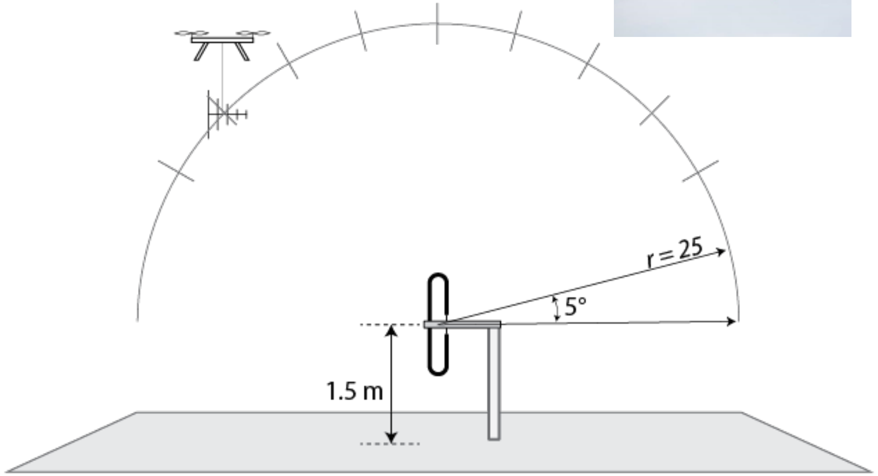
$$L < (2)(0.62)\sqrt{\frac{D^3}{\lambda}}$$



Measured reflection coefficients of the antenna at different heights above the ground plane at the Keysight site.

Radiation Pattern Measurements

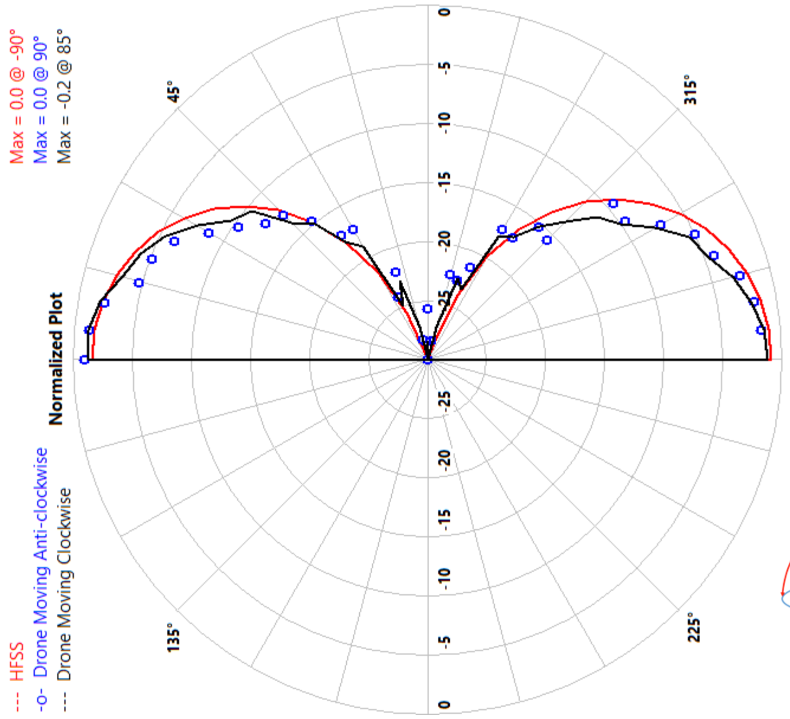
- The 60 MHz antenna is setup on the ground plane vertically and the drone is used to measure elevation pattern cuts.
- The drone has approximately a **0.25 meter radius spherical error** related to its expected location during flight using differential GPS telemetry.
- **Friis path** loss equation gives approximately **0.45 dB** of error at 0.25 meters.
- It's worth noting that **polarization losses** due to pitch or roll of the drone are negligible compared to its precise location error.

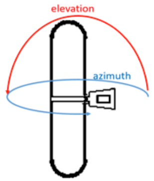


A diagram showing a far-field normalized pattern measurement cut. On the left is a picture of the drone with the receiver and the biconical antenna used for the measurement.

Radiation Pattern Measurements & Simulations

- The drone recorded several radiation far-field pattern measurements for different cuts.
- Radiation patterns for measurements and HFSS simulations for the **90° azimuthal** cut.
- Several radiation pattern cuts are measured and simulated at **0, 45, 135, and 270 degrees in azimuth**, for all possibilities and for different drone travelling directions.
- All the cases show **good agreement** with simulation.

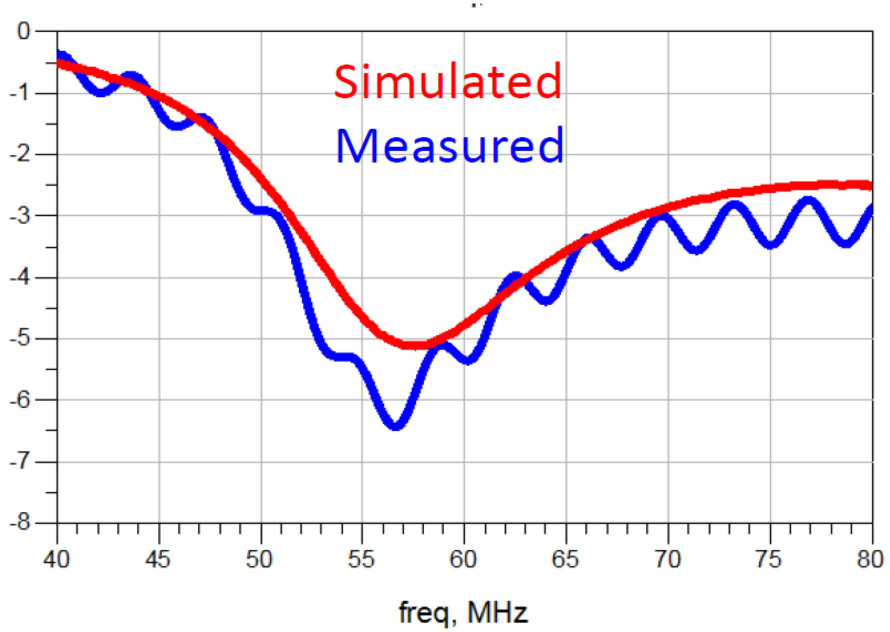




Normalized gain comparison among several independent measurements of the same cut to estimate the repeatability error for 90° cut.

S-parameters Comparison

- **Measurements versus simulation** when the center of the antenna is about 3 meters above ground.
- **Ansys's HFSS** is used to calculate the complex reflection coefficient or alternatively the input impedance of the antenna, without the matching network.
- Measured S-parameters of the matching network are cascaded with the input S-parameters of the antenna to obtain the combined reflection coefficients of the antenna.
- **Good agreement** between measurements and simulation at 3 meters above the ground.



Measured (blue) and simulated (red) for vertically polarized dipole prototype located 3 meters above a ground plane as measured at the Keysight OATS site.

Conclusions

- It is possible to make use of an **OATS** with properly equipped **drone/unmanned aerial system** to make meaningful antenna pattern measurements at low VHF frequencies
- Verification of this methodology/technique was made comparing the data collected with HFSS and NEC simulations which **matched quite well**
- Further investigation of refining the measurement technique and hardware e.g. improving position accuracy of the drone, etc. may improve measurement accuracy
- It is worth noting that what is presented in this paper is a **measurement concept** and its verification and validation using simulation

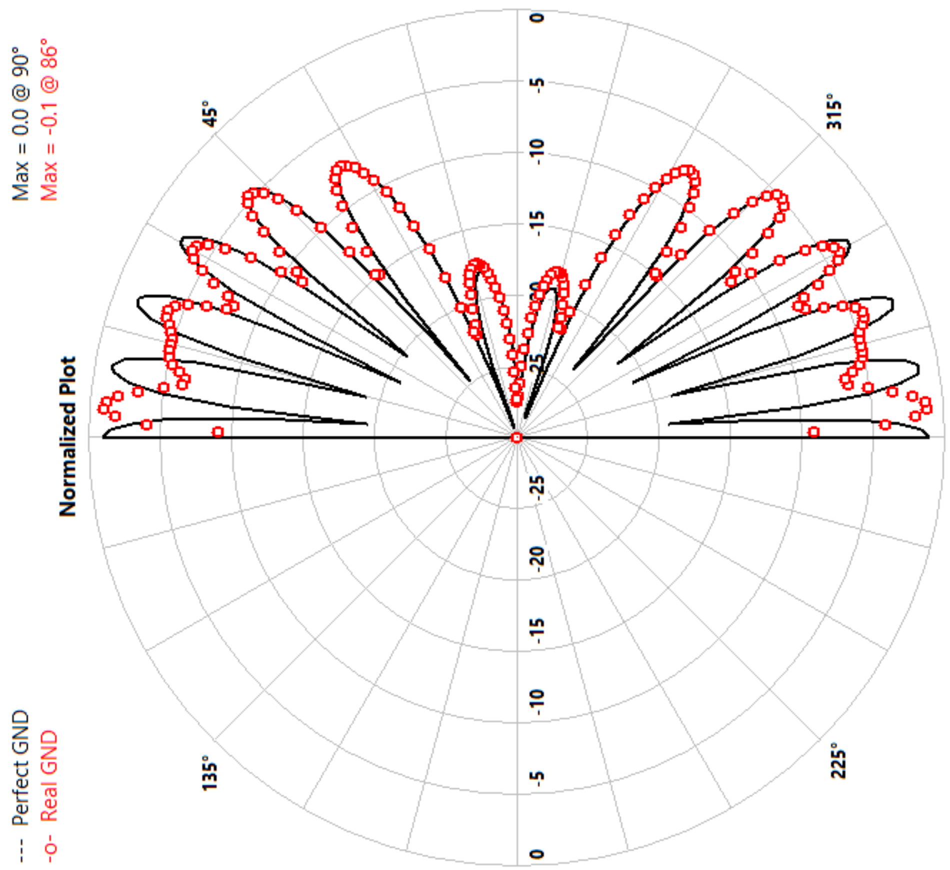
Acknowledgment

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The authors would like to thank Max Dreher, Chris Gormley, Brandt Langer, Kendall Petersen, Nate Potts, and Travis Wilson from Keysight for their patience and help with our measurements.

Backup

- The effect of antenna distance from ground is studied using both **HFSS and NEC2.**
- The radiation pattern predicted by NEC2 starts to have several lobes as we go farther away from the ground plane.
- The **number of nulls** equals the distance divided by quarter wavelengths at 60 MHz, which is consistent with the ground-bounce phenomenon.

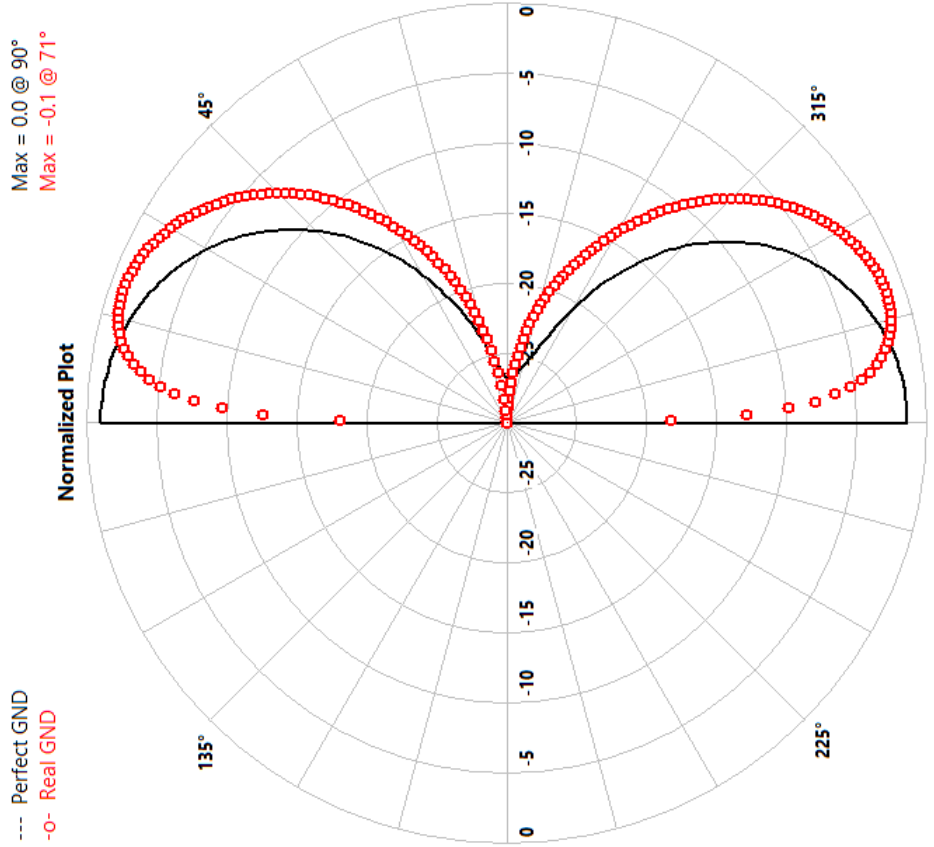


Simulated antenna pattern using NEC at 14.75 meters above a ground plane. In red, a lossy ground plane is considered while in black a simulated perfect ground plane is used.

Backup

- Simulations are carried out for a **perfect ground** (black curve), which is similar to our test case, and for a **real ground** (red curve) that considers losses such as a grass field.

- The simulations suggest to **measure the antenna about 1.25 meters** above the ground plane, from the center of the antenna, or just a few centimeters off the ground from the antenna's lower end when positioned vertically.



Simulated antenna pattern using NEC at 1.25 meter above a ground plane. In red, a lossy ground plane is considered while in black a simulated perfect ground plane is used